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A method and a device for selecting and dimensioning measures in case of instability in an electrical power system

5 Technical field

The present invention relates to a method for protecting an electrical power system which is in an unstable condition and which is heading for voltage collapse, as well as for
10 selecting and dimensioning those measures that need to be taken for the electrical power system to attain voltage recovery and return to a stable condition.

The measures that may need to be taken according to the
15 method are controlled disconnection of certain load from the electrical power system or connection of additional power to the electrical power system, or a combination of these measures.

20 The invention also relates to a device for carrying out the method according to the invention, wherein the device comprises electronic measuring and control equipment intended to be used in an electrical power system.

25 Background of the invention and prior art

It is already known to plan, dimension and design an electrical power system for normal as well as disturbed operation by using dimensioning criteria, set in advance, for
30 various system quantities, such as operating voltage and mains frequency.

The voltage levels of the electrical power system at different network points or nodes constitute a measure of the
35 condition of the electrical power system, that is, the ability of the system to continue to supply the loads of connected areas with the desired power. During normal operation, the operating voltage at a network point or a node is to lie within a pre-allowed interval, normally within a few

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percent of the stated nominal voltage. Examples of normally
occurring nominal voltages are 400 kV, 130 kV and 50 kV. The
construction, function, operation, automatic and protective
equipment of an electrical power system are described, as

5   far as Swedish conditions are concerned, in our Swedish
patent SE 0101061-0 entitled "An electric power plant with
means for damping power oscillations".

In case of disturbances in the electrical power system,
10   preferably when the transmission capacity is weakened or
decreasing, but also in the event of loss of electricity
production plants or loss of other components with a
voltage-controlling function, and combinations of these, the
voltage distribution in the electrical power system is
15   changed in such a way that the voltage level across the
loads drops, which leads to a drop also of the voltage level
in the transmission network. The corresponding phenomena may
also arise in case of too fast a load increase.

20   Common in both cases is that the electrical power system is
not capable, in the steady state, to supply the load connec-
ted to the network. Unless measures are taken, the different
component-protective functions of the electrical power sys-
tem, which are adapted to react on changes in voltages
25   and/or currents, will successively disconnect components in
the electrical power system. Normally, disconnection of
transmission lines is the first thing that happens. Discon-
nection of components may occur over time, from a few
seconds up to several hours.
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A typical scenario is that the voltages at the measuring
points of the impedance-measuring line protection device
decrease and the currents increase, whereby the most sen-
sitive measuring zone of the protection device disconnects
35   the line in question. The remaining lines, in the network
thus weakened, are then further loaded, whereby more trans-
mission lines are disconnected. This proceeds until the re-
maining electrical power network is able to maintain a con-

stant electricity operation and achieve a balance between
production, transmission capacity and load.

Examples of events such as those mentioned above are the
5   major power failures in the USA/Canada, Sweden and Italy in
2003. Scenarios such as those described above are, of
course, desirable to avoid and there are a plurality of
methods to detect incipient voltage instability in an elec-
trical power system. In such systems, voltages and reactive
10   power flows are measured, and devices for limiting the cur-
rent on generators for detecting voltage instability have
also been used, see, for example, Ingelsson, Karlsson,
Lindström, Runvik, Sjödin: "Special Protection Scheme
against Voltage Collapse in the South Part of the Swedish
15   Grid", CIGRE Conference, Paris, 1996.

Still more advanced detectors, with or without possibilities
of communication, have been presented and tested. One such
example is the so-called VIP algorithm (Voltage Instability
20   Predictor) described in Begovic, Milosevic, Novosel: "A
Novel Method for Voltage Instability Protection", Procee-
dings of the 35th Hawaii International Conference on System
Sciences, 2002. This system compares the impedance at a
certain network point, in the direction of the load, with
25   the impedance in a direction towards the production source.
The relation between the load impedance, thus measured, and
the source impedance may then be used as a measure for de-
tecting incipient voltage instability.

30   One common method, which is efficient in this context, for
mitigating or preventing voltage instability, after such
instability has been detected, is to disconnect parts of the
load in the network. By disconnecting a load corresponding
to some ten per cent of the total load in the inflicted
35   area, the remaining load may often be adequately supplied.
By intentionally and in a controlled manner disconnecting
some load objects in a stressed operating situation, at
least the operation of the major part of the inflicted area
is saved, while at the same time the transmission network is

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kept energized and intact. The disconnected loads may be
energized more rapidly again when stability has been resu-
med, for example by switching operations in the network and
start-up of local electricity production.

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By selecting and determining in advance what load objects
are to be disconnected and in what sequence, a possibility
is obtained of selecting objects such that the harmful
effects in the system are limited. A frequency-controlled

10   load disconnection for disconnection of load objects at too
low or decreasing frequency is already available in most
electrical power systems, that is, when the balance between
actual electricity production and the desired consumption
has been disrupted, for example in case of a major loss of

15   production.

Other measures than load disconnection, such as the connec-
tion of shunt reactors and shunt capacitors, the connection
of emergency power via dc links, etc., may also be used.

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Existing non-connected electric power-generating objects
cannot be connected to the transmission network if the line
voltage is lower than a lowest value given in advance. For
this reason, it may be necessary to disconnect part of the

25   load such that reserve power plants may then be connected.
These reserve power plants may then be used to increase the
reactive generation and additionally increase the line vol-
tage. In addition, they are to deliver active power and make
it possible again to connect the previously disconnected

30   load without the balance between production and consumption
being lost.

With a view to designing a selective protection against vol-
tage instability, based on the use of load disconnection,

35   primarily three questions need to be answered in view of the
prevailing operating situation:

    1)   When should the load disconnection take place?
    2)   Where should the load disconnection take place?

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3)   How much load should be disconnected?

The voltage level is normally a sufficiently good criterion
for determining where the load disconnection should take
5   place.

Disconnection may take place "without unnecessary delay",
that is, as quickly as possible after a margin has been
allowed for reserve disconnection of a shunt fault, that is,
10   short circuits and ground contacts. The speed should also be
adapted to the speed of the on-load tap changer control of
the power transformers connected in the vicinity thereof.
The time delay should normally be a few seconds.

15   However, the extent of the load disconnection is more diffi-
cult to determine. One method is to proceed by trial and
error by disconnecting one or more loads, load areas, at a
time. This is a relatively slow method since the system
response to each disconnection must be awaited.
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Another method is to use a comfortable margin and disconnect
a larger number of loads. The disadvantage of such a method
is that an unnecessarily large part of the load is discon-
nected and also that this involves a risk of obtaining high
25   voltages in the electrical power system.

At present, there is no known method of dimensioning or de-
termining the magnitude of a necessary load disconnection,
when the need of such a measure has been detected. The ful-
30   filled criteria normally result directly in load disconnec-
tion via a preselected circuit-breaker function with a
suitable time delay, typically a few seconds.

US 6,219,591, "Voltage instability predictor (VIP) – method
35   and system for performing adaptive control to improve vol-
tage stability in power systems", shows a method for detec-
ting that the power system, or parts thereof, is/are heading
for instability. However, the method only mentions the need
of load disconnection in general, as a suitable measure for

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how this threatening instability is to be cancelled or miti-
gated.

The invention according to US 6,242,719, "Applications and
5   methods for voltage instability predictor (VIP)", is a
further development of the invention according to US
6,219,591, which, among other things, relates to masked
transmission networks. However, none of these publications
suggests any measure of magnitude of that quantity of load
10   disconnection that is required for stabilizing the system.

Several patent specifications deal with the VIP algorithm,
which suggest stability measures of various kinds and pre-
dict an imminent voltage collapse, but do not suggest the
15   extent of or magnitude of the load disconnection that is
necessary to prevent a power failure or a collapse in the
electrical power network.

Objects and most important characteristics of the invention

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The object of the present invention is to solve the above-
mentioned problems and suggest a method for determining the
extent of the load that needs to be disconnected from the
electrical power network or the power that needs to be supp-
25   lied to the electrical power network for the purpose of
achieving voltage recovery in the electrical power network
and to cause the system to resume a stable state.

The above object and further objects are achieved according
30   to the invention by a method according to claim 1, by a de-
vice according to claim 23, and by a computer program accor-
ding to claim 25.

Brief description of the accompanying drawings

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The invention will be described in greater detail below with
reference to the accompanying figures.

Figure 1 shows, in principle, an electrical power system.

Figure 2 schematically shows an electrical power system com-
prising a transformer station, loads, switching means and a
unit according to the invention.

5   Figure 3 is a simple flow diagram of the method according to
the invention.

Figure 4 shows a priority table of various loads included in
the electrical power system which may be disconnected, and
10   their mutual order.

Figure 5 shows a concrete arithmetical example of a load dis-
connection.

15   Description of preferred embodiments of the invention

In the description, the same designations are used for the
quantities that occur in lines, protective devices and loads,
as for the measured values and signals/calculated values
20   which correspond to these quantities and which are supplied
to and treated in the protective device.

Figure 1 shows a single-line diagram of an electrical power
system 1 comprising an equivalent generator G which delivers
25   the voltage U_G to the electrical power system and which has a
source impedance Z_S, as viewed from a busbar 3. The busbar 3
functions as a nodal point in the electrical power network
and collects and distributes the electric power flow.

30   The load Z is here divided into one part which is to remain
undisturbed, Z_L, and one part which is to be disconnected,
Z_{LS}, in case of voltage instability. Both that part of the
load Z_{LS} which is to be disconnected and that part of the load
Z_L which is to continue to be connected are normally consti-
35   tuted by a plurality of line bays with associated circuit
breakers CBa,b.

A calculation of the voltage U_G behind the source impedance Z_S
and the prevailing load impedance Z is made according to

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equations (1) and (2) below, where I is the current into the
busbar 3 under consideration from source G, and U is the
voltage prevailing on the busbar 3 under consideration:

$$U_G = U + I \cdot Z \qquad (1)$$

$$Z_L(// Z_{LS}) = \frac{U}{I} \qquad (2)$$

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If U_T designates the desired voltage, after load disconnec-
tion, an equation (3) for voltage division is obtained as
follows:

$$\frac{U_G}{Z_S + Z_L} = \frac{U_T}{Z_L} \qquad (3)$$

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Equation (3) gives Z_L. Thereafter, Z_{LS} may be calculated with
the aid of equation (2), and thereafter the corresponding
values of active and reactive power, P_{LS} and Q_{LS}, respective-
ly.

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As soon as the required amount of load disconnection has been
determined, a trigger impulse is sent to the switching mem-
ber(s) CBa,b which best correspond(s) to the calculated re-
quired load disconnection. In this context, different dis-
20 connection costs or mutual priorities for different types of
loads may also be taken into consideration. Information about
the power consumption of different loads may be estimated
with differing degrees of accuracy, from fixed values, which,
for example, are updated in view of the season, to real-time
25 measurements. Then, loads are chosen from a priority table
established in advance; see Figure 4, which shows the
priority of the loads and the power levels occurring.

The value of U_G may alternatively be regarded as known, or be
30 calculated regularly, for example every 5th minute, whereupon
the calculation of the change of the source impedance Z_S dur-
ing a voltage instability scenario becomes trivial.

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The source impedance Z_S is calculated based on changes in
voltage and current during, for example, tap-changer control
or connection with shunt components. The source impedance Z_S
may also be estimated by measuring current and voltage at
5   different load levels. If the above-mentioned continuous up-
dating of the magnitude of the source impedance for some rea-
son should be considered too complex, the source impedance Z_S
may also be assigned a definite value. In transformer sta-
tions from transmission level (or subtransmission level) to
10   medium-voltage level, knowledge of the size and short-circuit
impedance of the transformers is often insufficient to esti-
mate the source impedance with an accuracy of ± 25 %, since
the short-circuit power of the transformer in such cases is
predominant and the short-circuit power of the rest of the
15   network has a minor influence.

Another way of determining the source impedance Z_S is to uti-
lize negative-sequence quantities for current and voltage as
well as assuming that the impedance of the source in relation
20   to positive- and negative-sequence currents, respectively, is
the same. In connection with the development of the VIP algo-
rithm, methods have been obtained for determining the source
impedance Z_S.

25   The method according to the invention may also be used step
by step, for example if the voltage did not turn out to be
the expected/calculated one at the nodal point in question
after the first disconnection phase or if the impedance in
supply networks increases and the voltage thus decreases at
30   the monitored point.

According to the invention, this is achieved by determining
the quantity of the load, or that part of the load, which is
to be disconnected on the basis of measured actual voltage
35   *and* desired voltage, at the node after the load disconnec-
tion.

With knowledge of measured and desired voltage, or voltage
recovery, as well as actual load and source impedance Z_S - or

a corresponding quantity such as, for example, source admit-
tance - the required load disconnection, for achieving the
desired voltage in the node again, may be obtained by a nor-
mal circuit calculation.

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Voltage recovery may, for example, be the difference between
voltage before load disconnection, that is, the "measured"
voltage, and voltage after load disconnection, that is, the
"desired" voltage, but it may also be defined as a percentage
10   of the measured voltage.

The load disconnection takes place by circuit-breaker tripp-
ing or by means of other switching members. It is also feas-
ible to use a centralized telecontrol system which, via a
15   communication channel, orders disconnection of certain indi-
vidual load objects, for example hot-water heaters, air-
conditioning plants etc. Such ordering may also take place
via a "price change", wherein certain loads, via the commu-
nication system, react automatically on a price change.

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In a preferred embodiment of the invention a table is used,
comprising all switching members which are included in the
load-disconnection system in question, which may comprise a
larger geographical area or a single transformer station. The
25   switching members are listed in the table in the order in
which they are to be disconnected from the electrical power
network in a position where instability has been detected.
The order of priority is based, for example, on the cost of
disconnecting the respective load.

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The table also contains information about the prevailing load
power for the respective switching member, that is, how much
power is disconnected during a switching-off operation with
the respective switching member. In this way, the automatic
35   control system runs through the list/the table to identify
and operate those switching members, taken by order of prio-
rity, which restore the desired voltage in the node and the
electrical power system with a minimum of costs/drawbacks.

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The table is regularly updated, for example where necessary, manually with regard to the order of priority, and automatically and in real time with regard to the load per switching member.

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The lines in the priority table in Figure 4 are sorted by order of priority according to column 2. From the dimensioning algorithm, the magnitude of the load that needs to be disconnected is obtained. In the table, one or more switching

10   members are selected in the order of priority, until the necessary amount of disconnected load has been achieved. Within the last selected group, the switching members may be selected so as to correspond to the necessary load in the best way.

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Figure 5 shows a concrete numerical example. The necessary load disconnection is here calculated to be 6 MW at $\cos\varphi = 20/\mathrm{sqrt}(20^2 + 8.9^2) = 0.91$. Both switching members with priority 1 are thus chosen and each disconnects its load, in

20   the same way as those switching members which have priority 2. The switching members which best correspond to the remaining three MWs are Br_Johanna and Br_Patrik.

In another preferred embodiment of the invention, the extent

25   of the necessary power addition is dimensioned in the same way as for load disconnection, for example via a dc connection, in order to obtain, based on a certain actual measured voltage, a certain desired voltage in the node in question after the power addition, with knowledge of the source impe-

30   dance in the node.

The method according to the invention may, at least partly, be carried out with the aid of program codes that are run in a processor or in a computer, and these program codes may be

35   stored on a computer-readable medium such as a hard disk, a diskette, a CD-ROM, or any other volatile memory.

Although the invention above has been described by means of a few different embodiments, the invention is not limited

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thereto but other embodiments and variants thereof are, of
course, feasible within the scope of protection of the
claims. Thus, it is feasible for a device according to the
invention to trigger an alarm signal in case of instability
5   in the system, based on a suitable criterion, and for the
load disconnection thereafter to be executed manually.

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